

# Follow-up of GW with *Fermi*-LAT and First Results from O4

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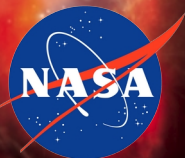
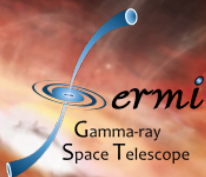
on behalf the *Fermi*-LAT Collaboration

11<sup>th</sup> International *Fermi* Symposium  
Plenary 4: *Multimessenger Sources*

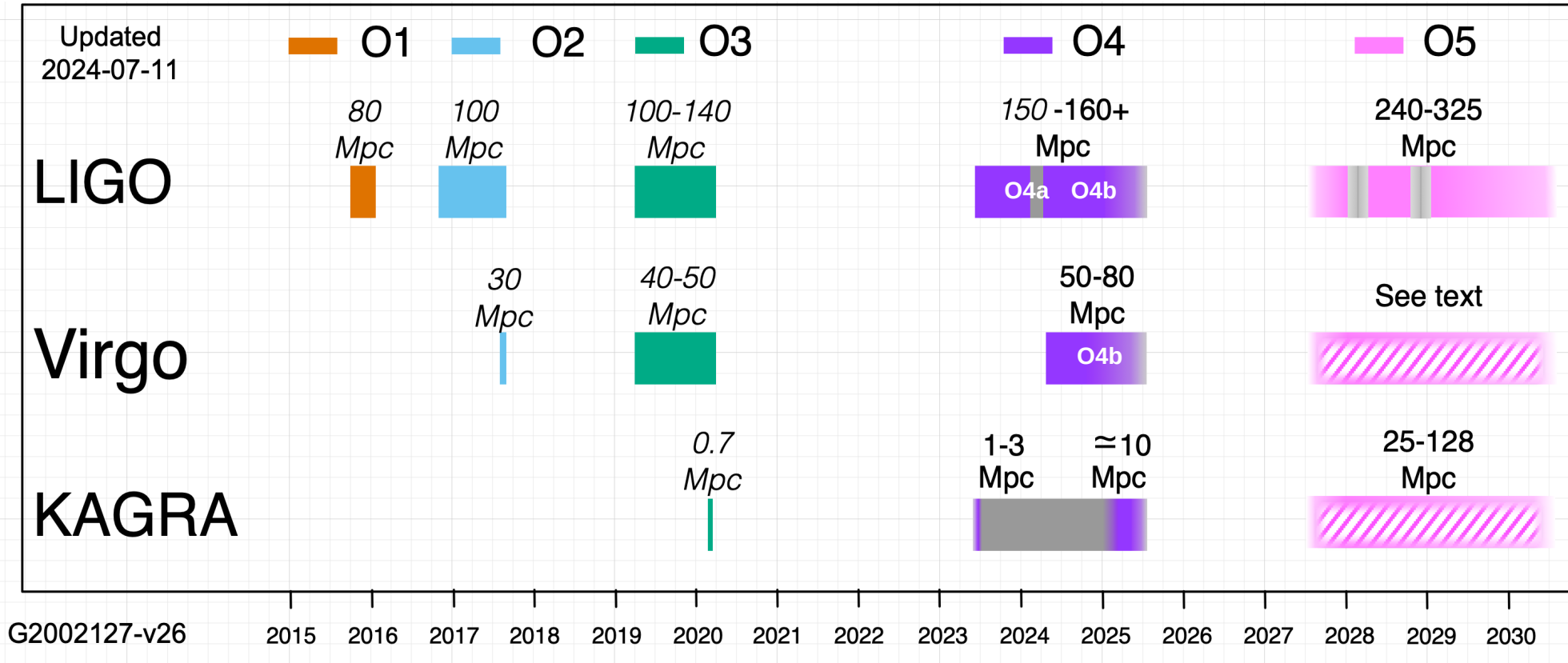
September 9, 2024



*Fermi* Gamma-ray Space Telescope

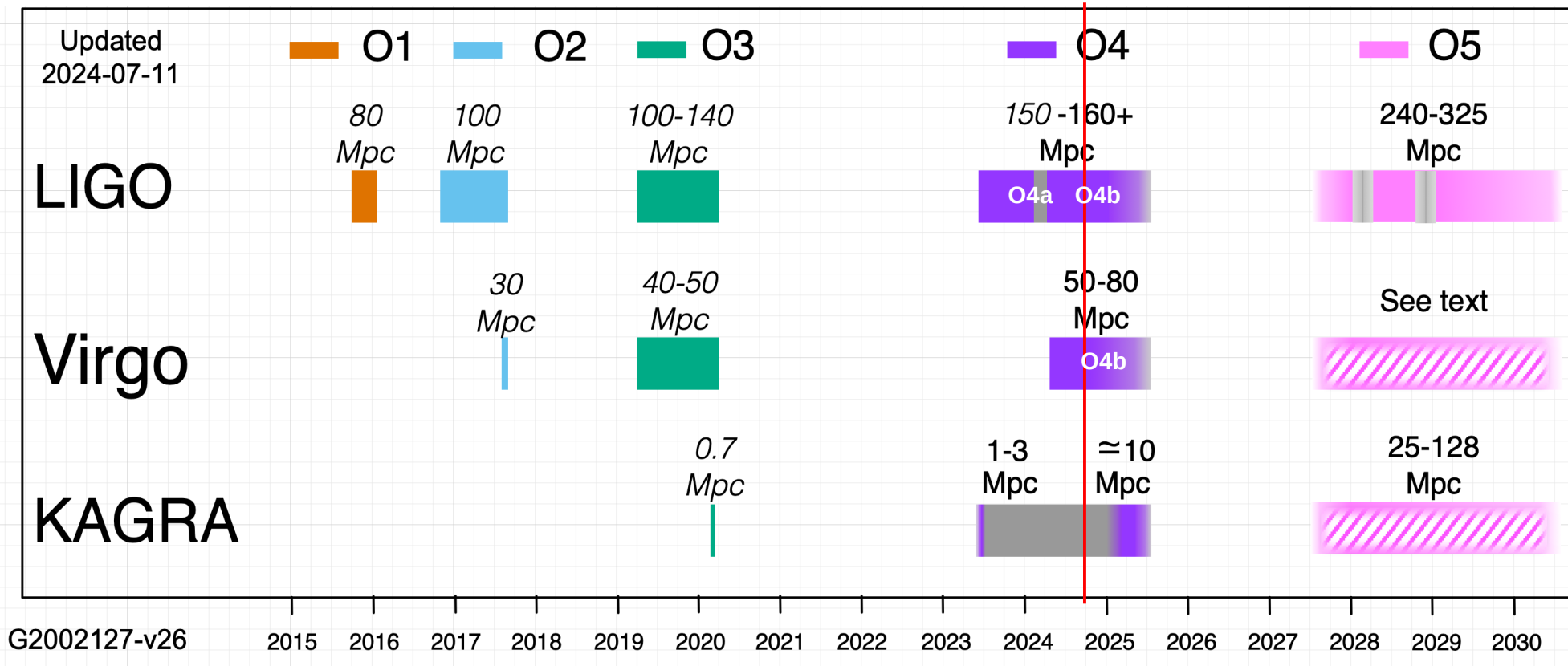


# LVK Observing Runs



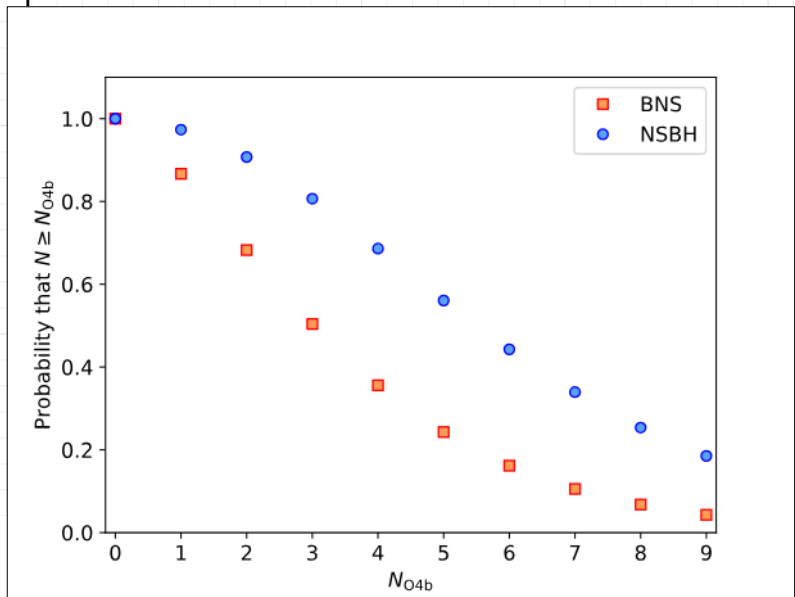
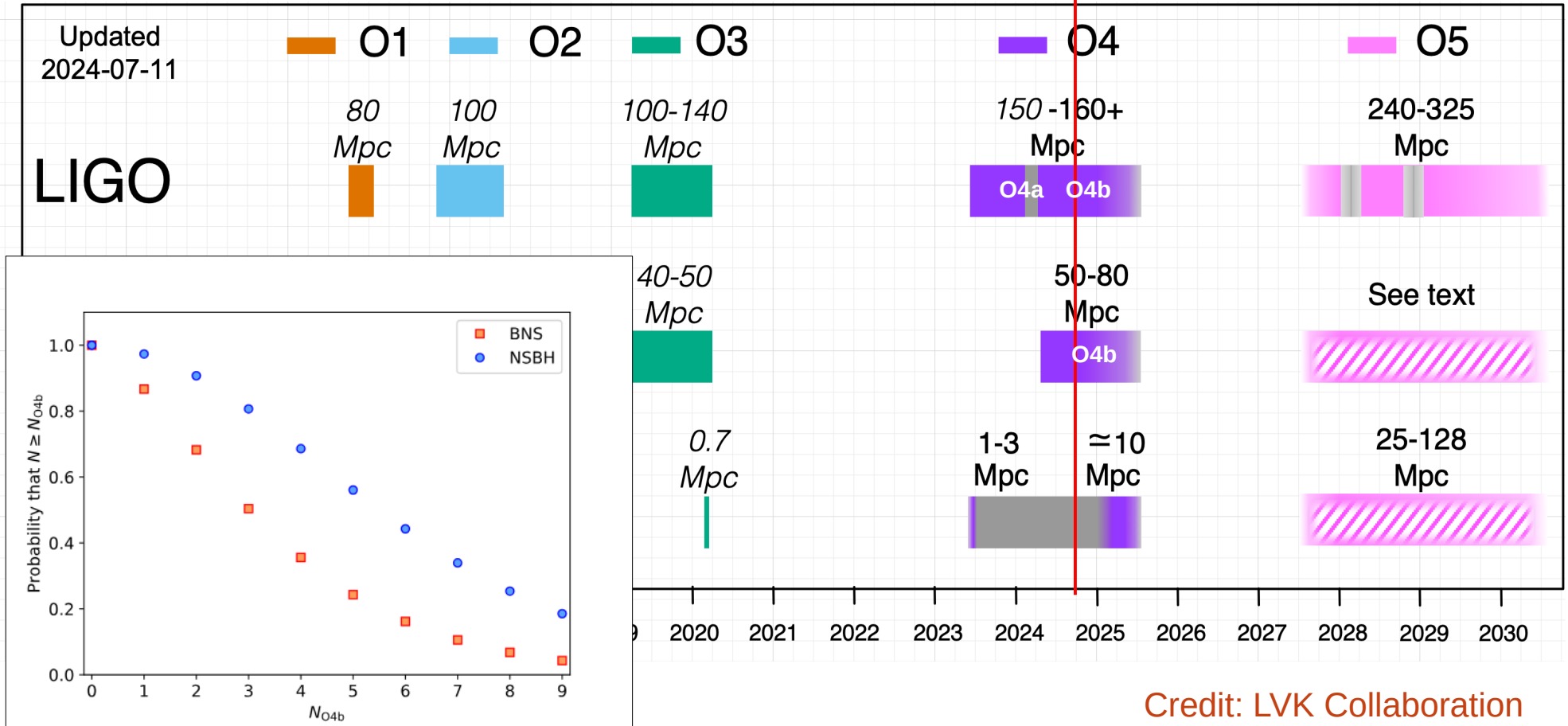
Credit: LVK Collaboration

# LVK Observing Runs

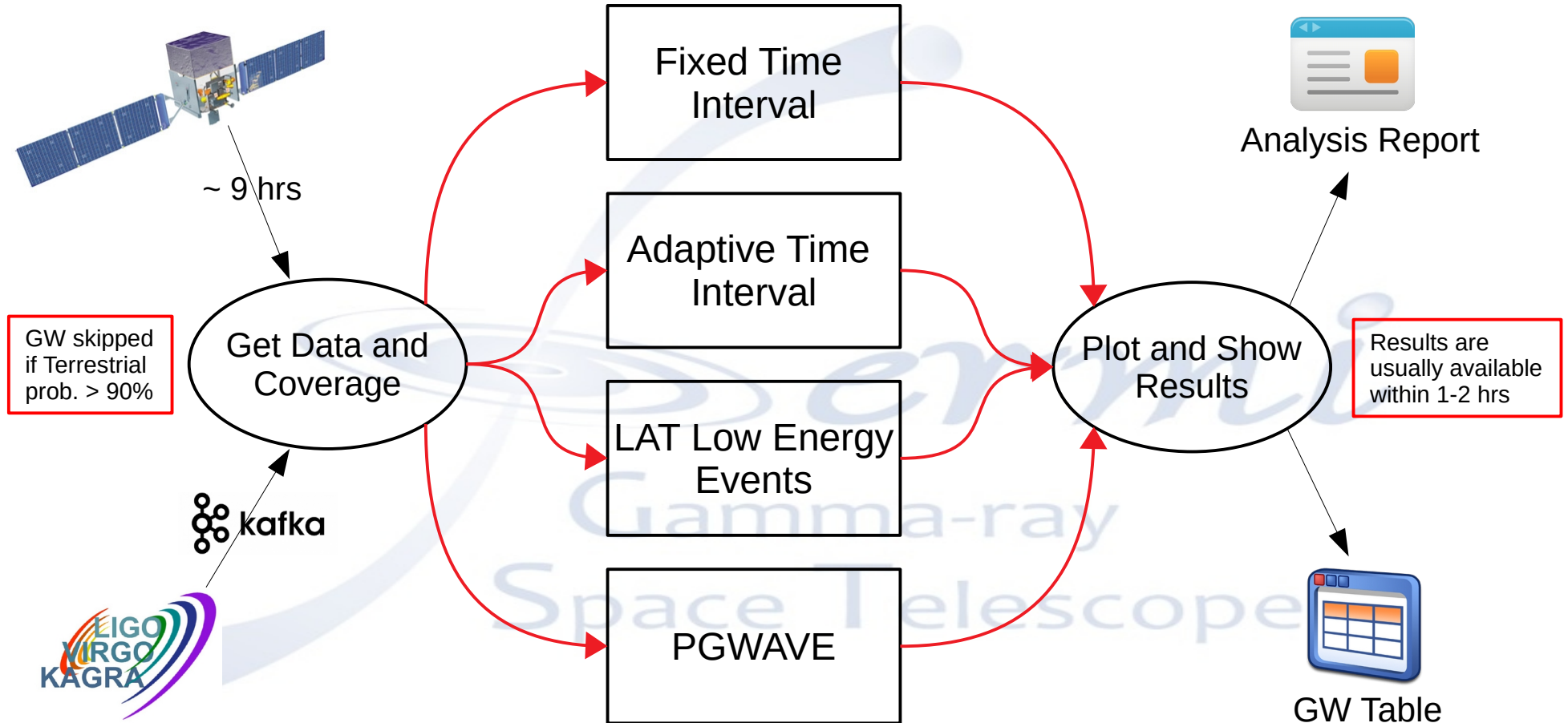


Credit: LVK Collaboration

# LVK Observing Runs



# LAT GW Follow-up Pipeline



# Implemented Analyses

Fixed Time Interval

- An independent unbinned maximum likelihood analysis is run for each pixel within 90% probability of the GW map in a **fixed time window** of 10 ks after the GW trigger

Adaptive Time Interval

- Similar to the FTI analysis, but the **ATI time window is optimized for each pixel separately** to get the largest exposure closer to the trigger time

LAT Low Energy Events

- LLE data ( $E < 100$  MeV) are extracted for each pixel of the GW map in the LAT FoV at the trigger time and the **significance of the light curves** is estimated respect to the background

PGWAVE

- PGWAVE is run over the count map to **discover candidate sources**, followed by a dedicated likelihood analysis if any of these are within the 90% probability of the GW map

# LAT GW Public Table

Stanford University

## Fermi-LAT Gravitational Waves Table

This page displays the outcomes of the Fermi-LAT automatic follow-up analysis pipeline used to search for electromagnetic counterparts of gravitational waves (GW). For a detailed explanation of the analysis techniques, please refer to [2017ApJ...841L..16V](#). Furthermore, the Fermi-LAT Collaboration has published additional papers on GW events such as [GW150914](#), [LVT151012](#) and [GW151226](#), [GW170104](#), and [GW170817](#)

All analysis results presented here should be considered preliminary, unless otherwise stated. If you have any questions, please write to [Niccolò Di Lalla](#).

Click on the following buttons to access the table associated with the corresponding observing cycle:

O3	O4
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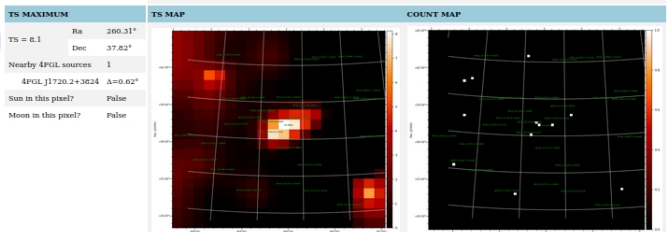
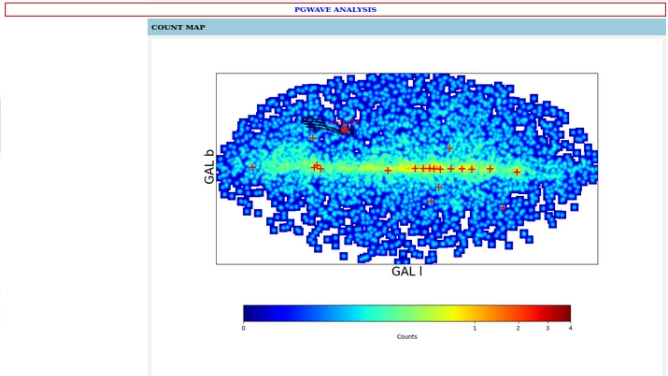
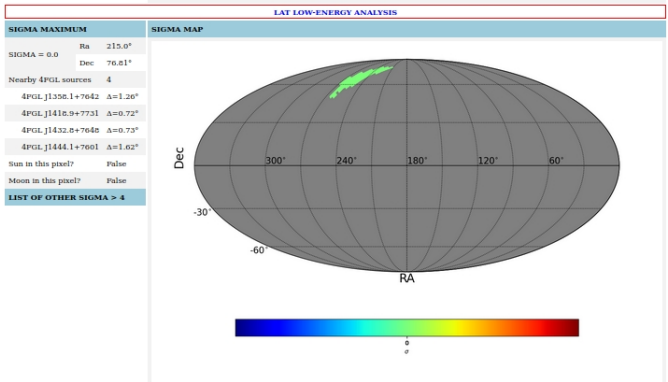
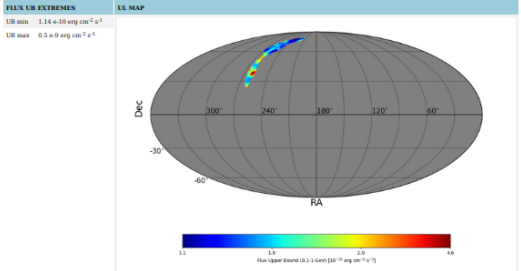
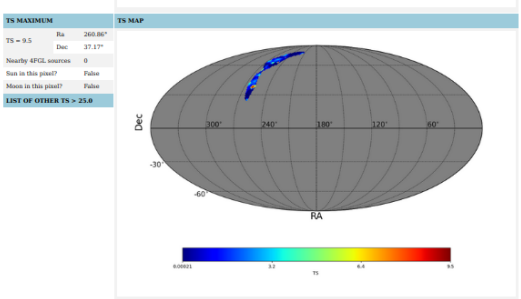
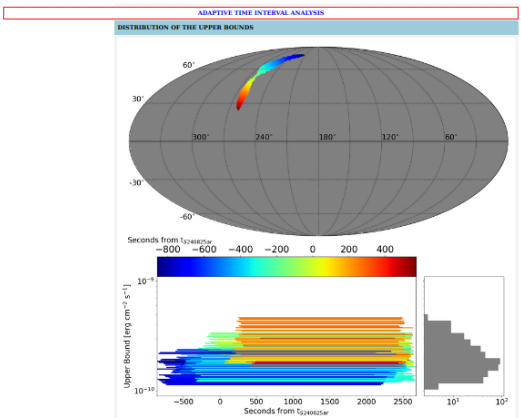
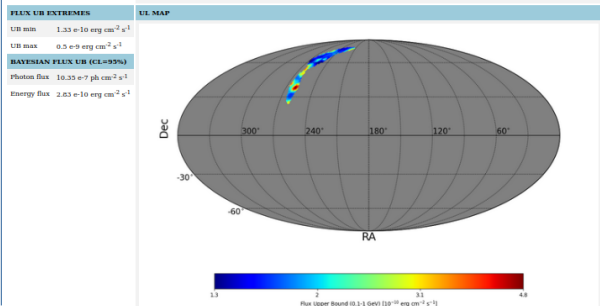
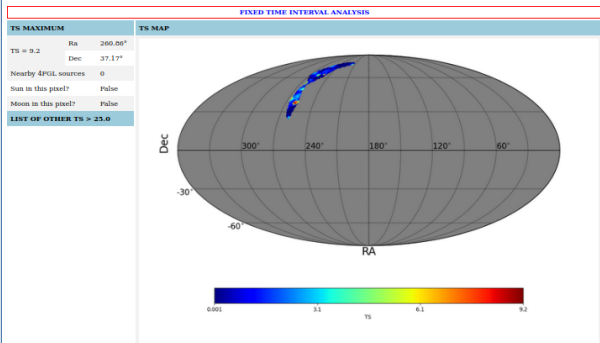
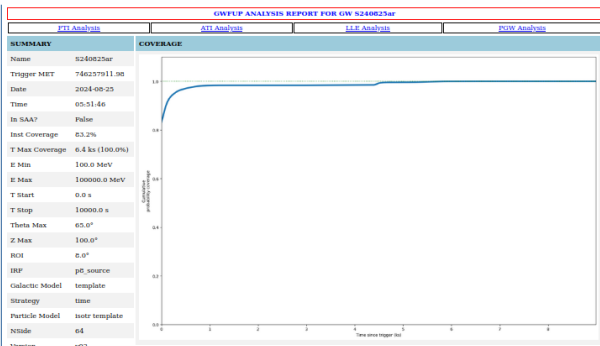
Stop your mouse cursor over the table headings to view a short explanation of the columns in the table or check the legend [here](#).

\* Information taken from [GraceDB](#) (LIGO-Virgo-KAGRA Collaboration).

Trigger Name*	Date*	Time (UTC)*	GraceDB*	FAR (Hz)*	Highest Probability*	Has NS? (%)*	Has Remnant? (%)*	Has MassGap? (%)*	Inst. Coverage (%)	FTI TS max	ATI TS max	Flux UB (erg/cm <sup>2</sup> /s)	Analysis report
S240902bq	2024-09-02	14:33:06	<a href="#">Link</a>	2.5e-09	BBH: 100.0%	0.0	0.0	0.0	0.0	10.2	9.8	5.3e-10	<a href="#">Link</a> (v02)
S240830gn	2024-08-30	21:11:20	<a href="#">Link</a>	6.3e-10	BBH: 89.1%	0.0	0.0	0.1	26.0	5.9	9.9	1.3e-09	<a href="#">Link</a> (v02)
S240825ar	2024-08-25	05:51:46	<a href="#">Link</a>	3.2e-09	BBH: 96.5%	0.0	0.0	7.1	83.2	9.2	9.5	2.8e-10	<a href="#">Link</a> (v02)
S240813d	2024-08-13	04:39:13	<a href="#">Link</a>	1.8e-18	BBH: 100.0%	0.0	0.0	0.0	27.4	12.4	11.1	1.4e-09	<a href="#">Link</a> (v02)
S240813c	2024-08-13	03:45:48	<a href="#">Link</a>	2.6e-09	BBH: 99.8%	0.0	0.0	2.8	41.8	19.5	23.4	6.9e-10	<a href="#">Link</a> (v02)
S240807h	2024-08-07	21:45:59	<a href="#">Link</a>	2.0e-11	BBH: 100.0%	0.0	0.0	28.3	39.9	<b>37.1</b>	<b>35.4</b>	5.7e-10	<a href="#">Link</a> (v02)
S240716b	2024-07-16	03:49:00	<a href="#">Link</a>	7.9e-16	BBH: 100.0%	0.0	0.0	0.0	6.6	22.5	19.6	5.7e-10	<a href="#">Link</a> (v02)
S240705at	2024-07-05	05:32:15	<a href="#">Link</a>	7.1e-16	BBH: 100.0%	0.0	0.0	0.0	2.4	7.9	8.1	6.5e-10	<a href="#">Link</a> (v02)
S240703ad	2024-07-03	19:13:55	<a href="#">Link</a>	1.2e-13	BBH: 100.0%	0.0	0.0	0.0	6.9	20.7	18.2	4.5e-10	<a href="#">Link</a> (v02)
S240630t	2024-06-30	10:17:03	<a href="#">Link</a>	1.9e-12	BBH: 100.0%	0.0	0.0	0.0	92.4	22.0	24.7	5.6e-10	<a href="#">Link</a> (v02)
S240629by	2024-06-29	14:52:56	<a href="#">Link</a>	3.2e-10	BBH: 91.5%	0.0	0.0	0.0	0.5	11.0	5.7	4.7e-10	<a href="#">Link</a> (v02)

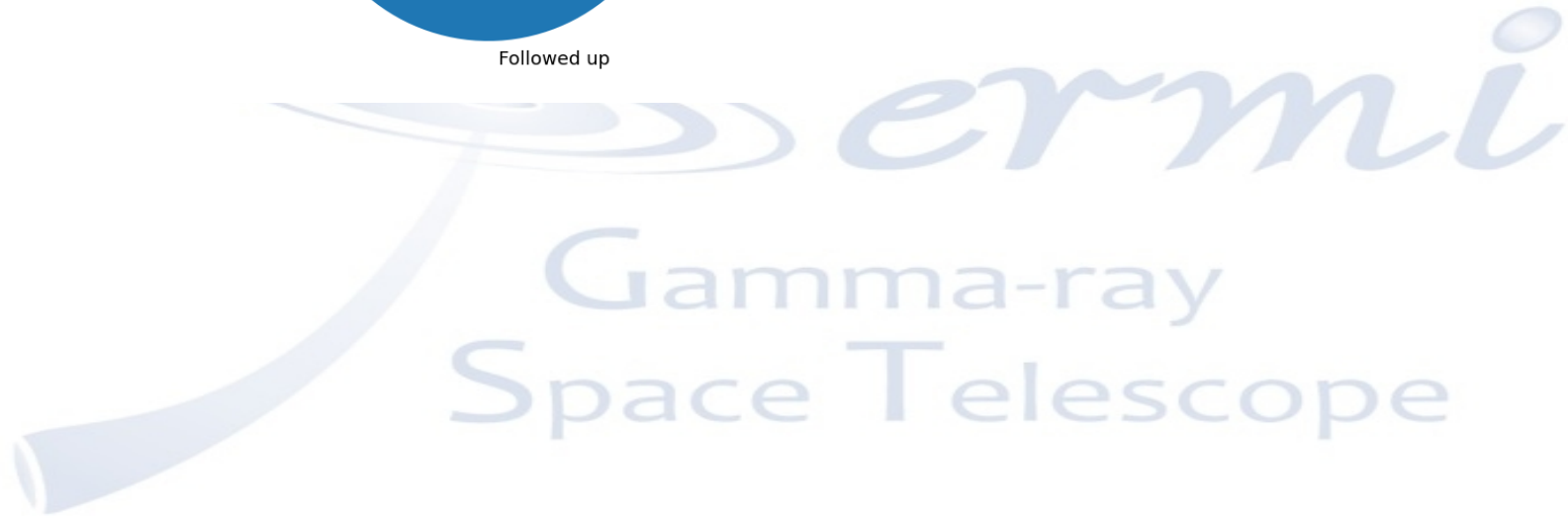
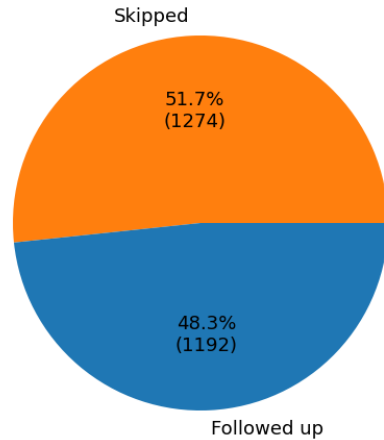
<http://fermigrb.stanford.edu/GWTable/>

# Analysis Report Page

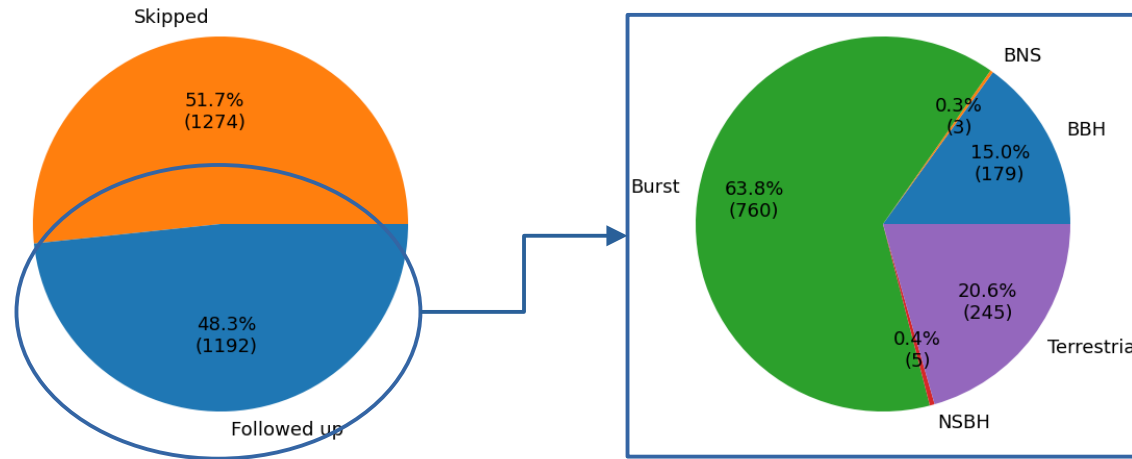




# O4a+O4b (so far) in Numbers

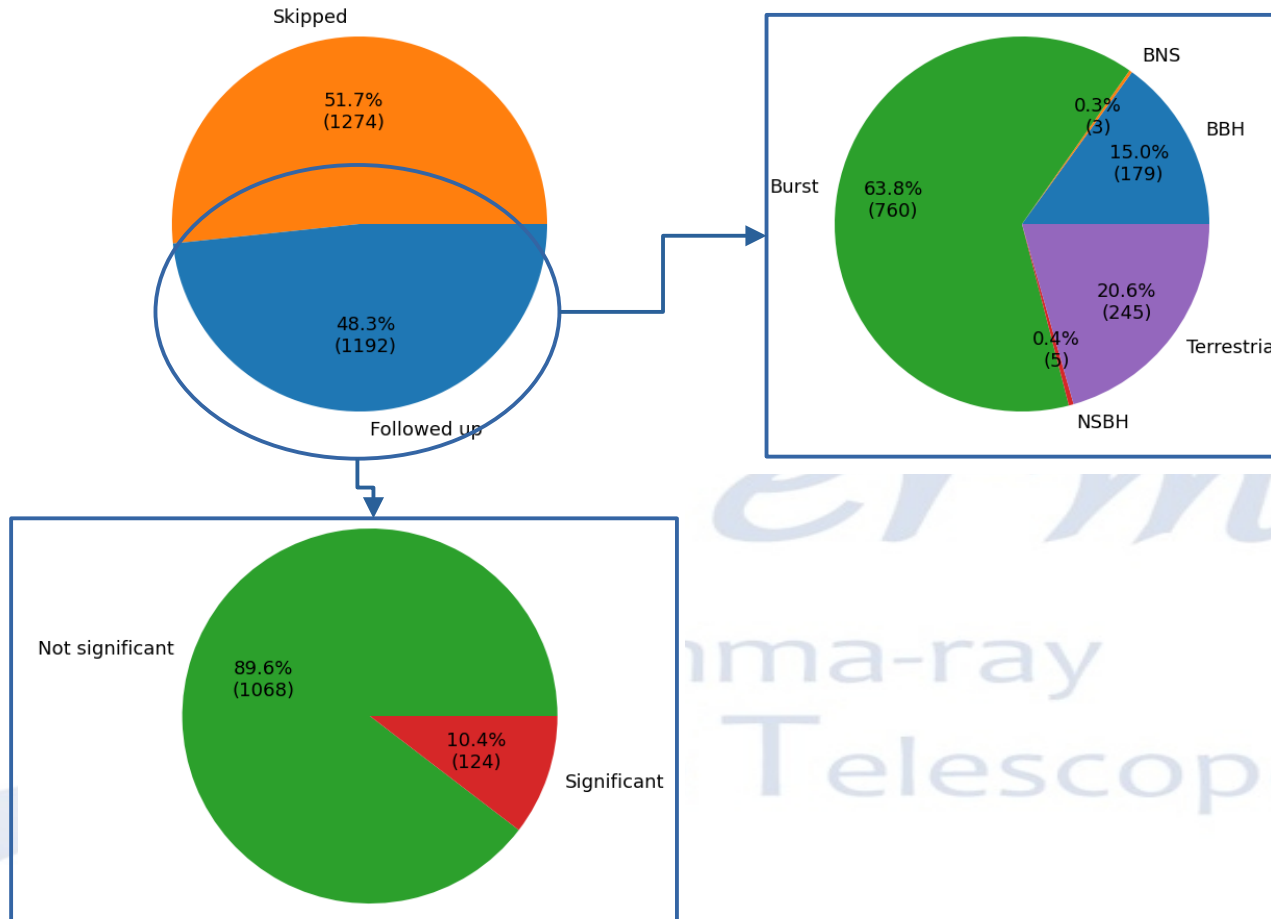


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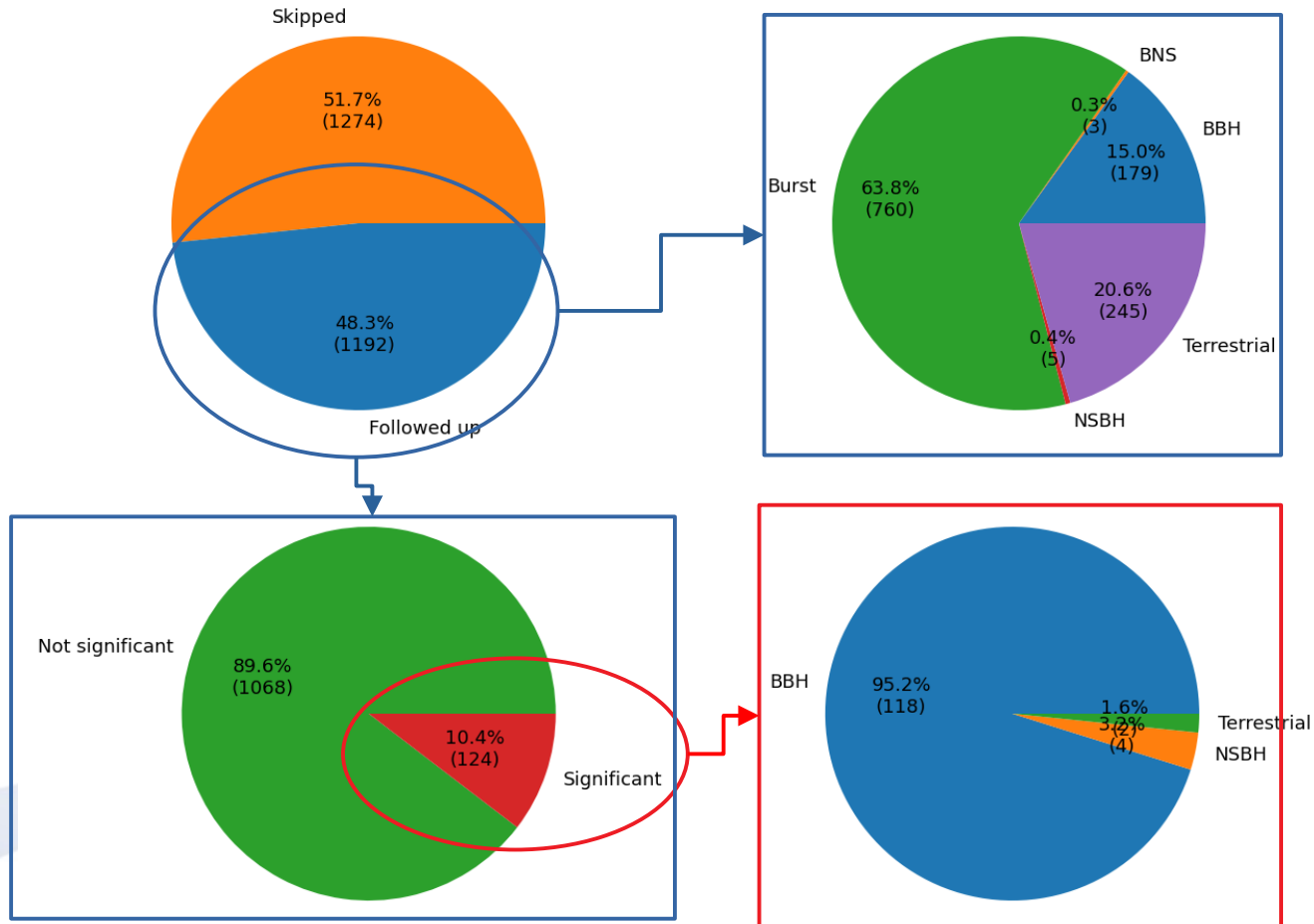


*fermi*  
Gamma-ray  
Space Telescope

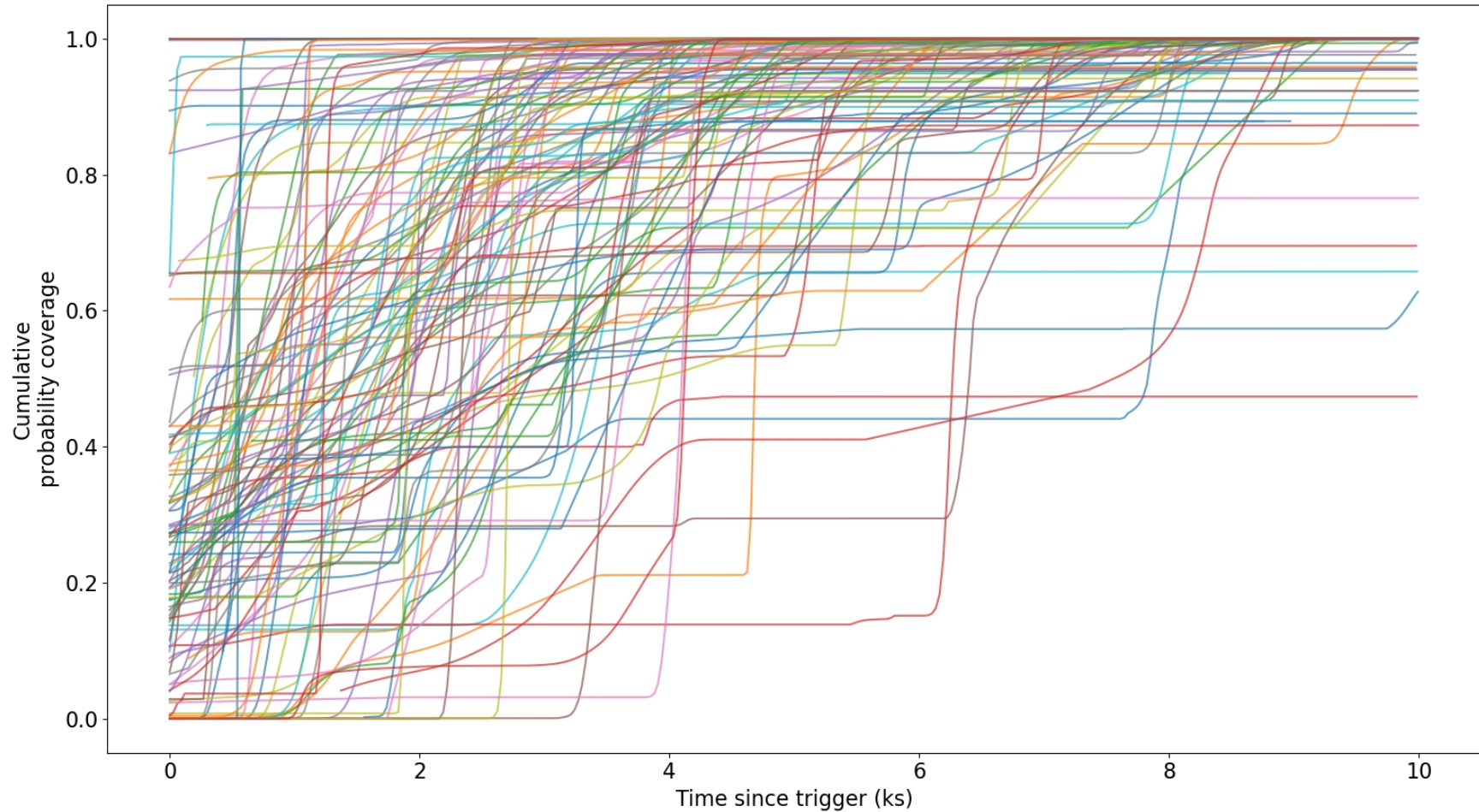
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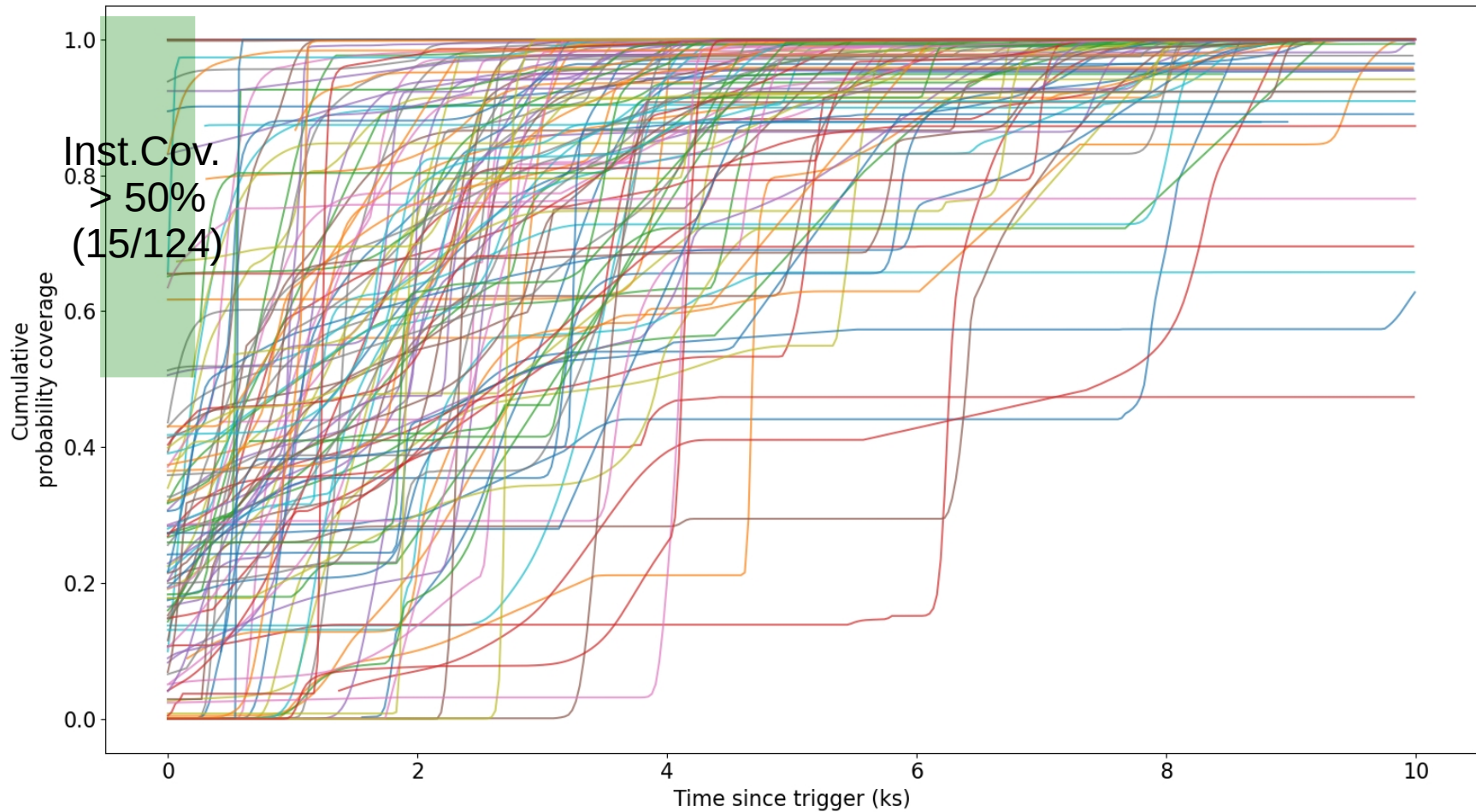
# O4a+O4b (so far) in Numbers



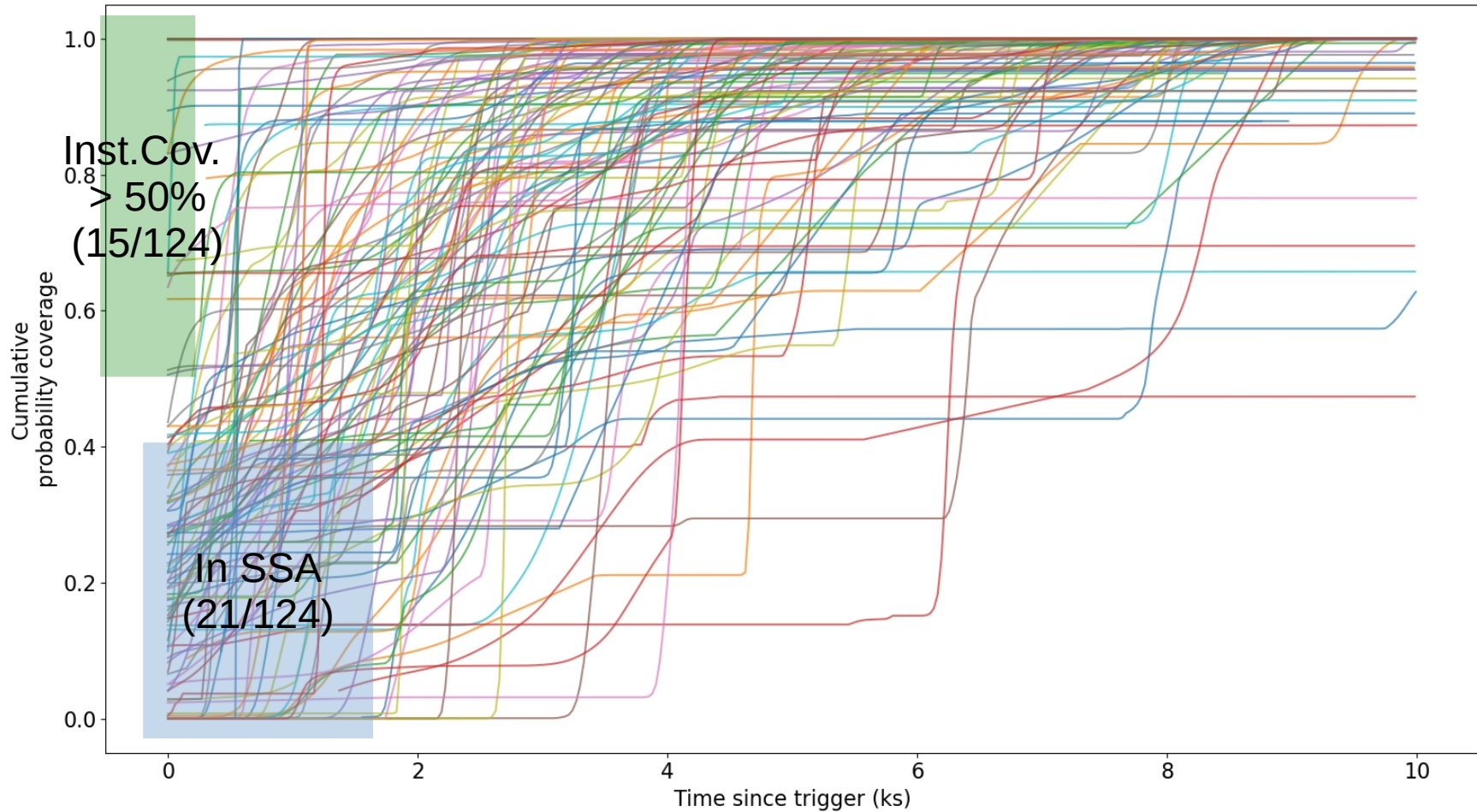
# Cumulative Coverage – Significant GW



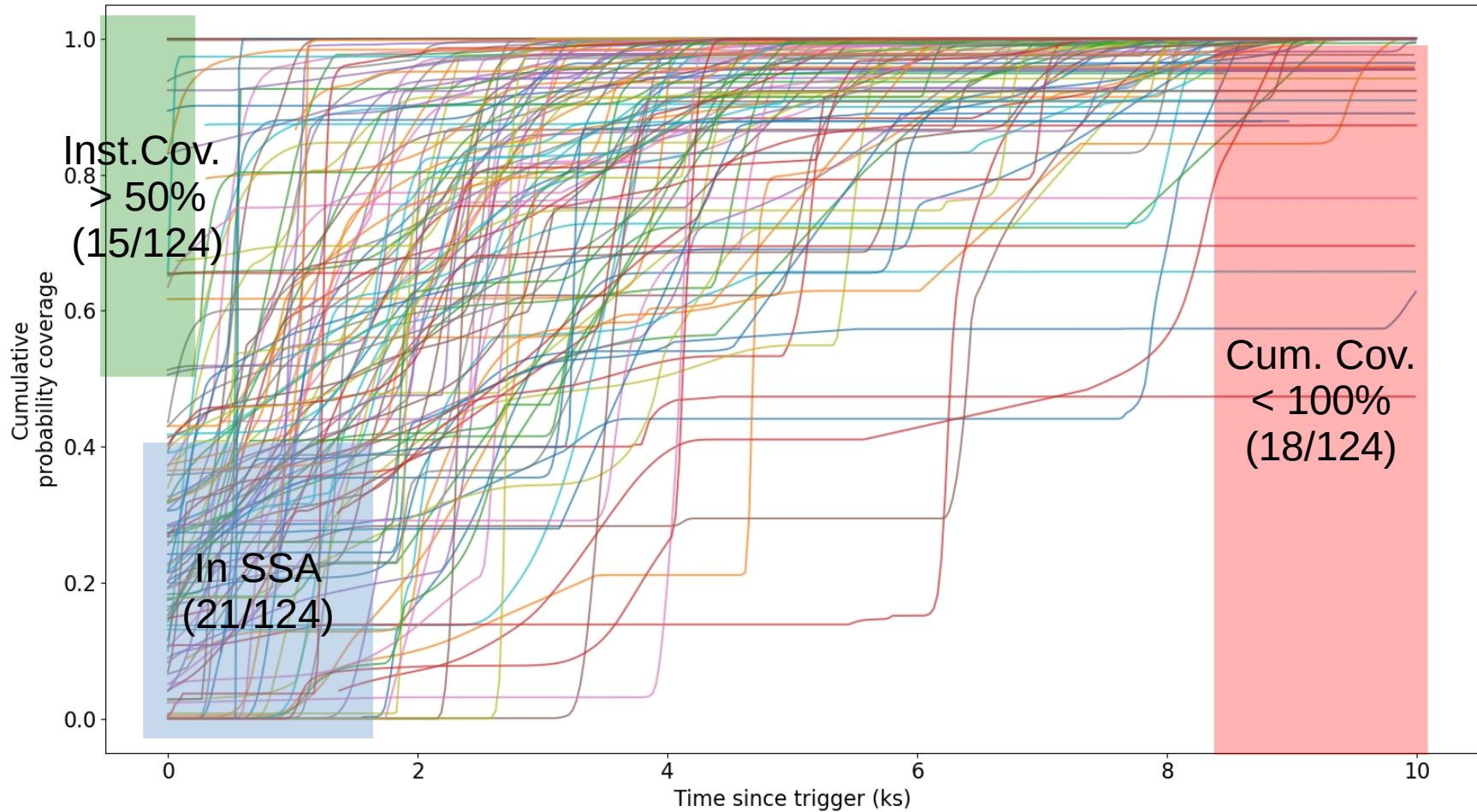
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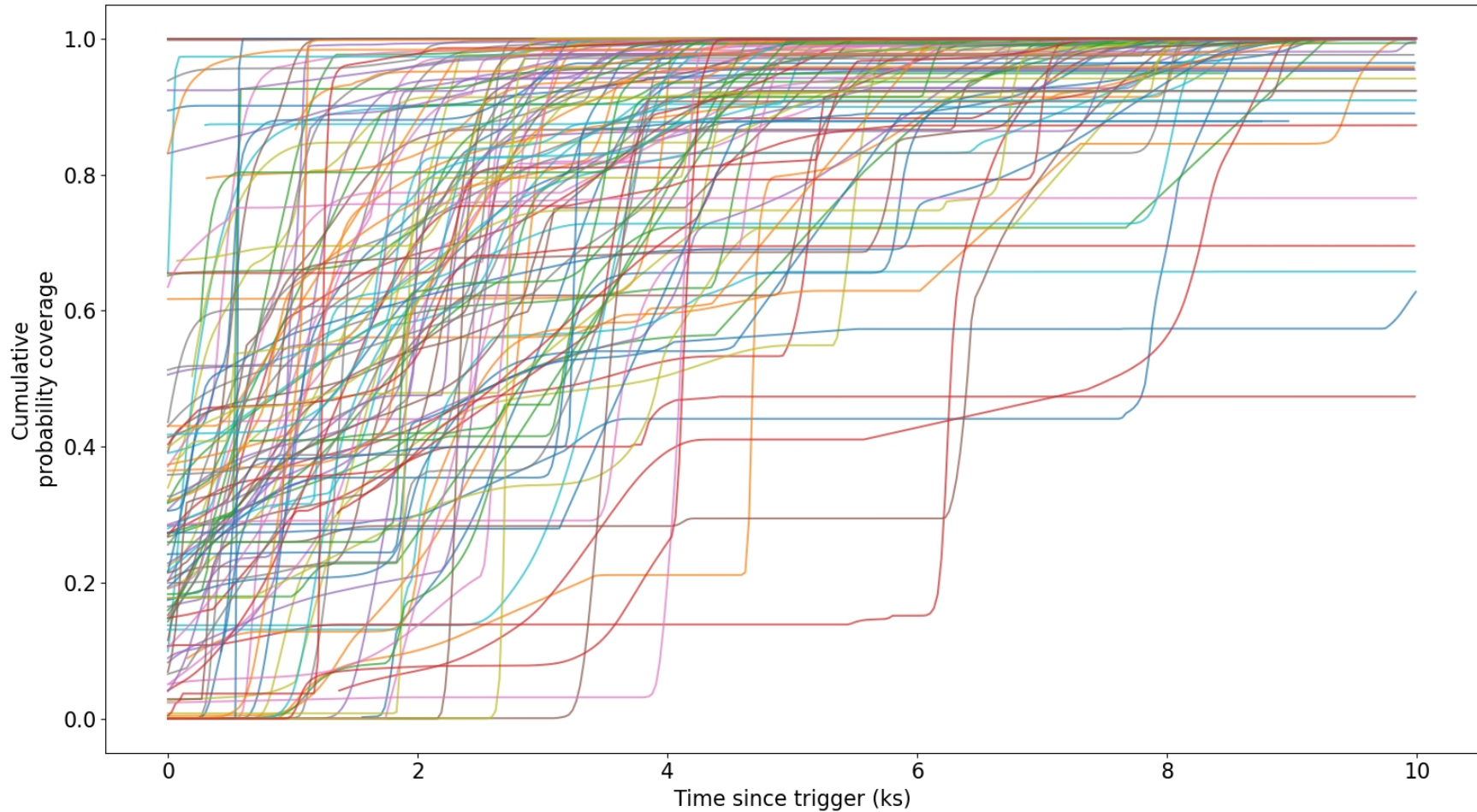


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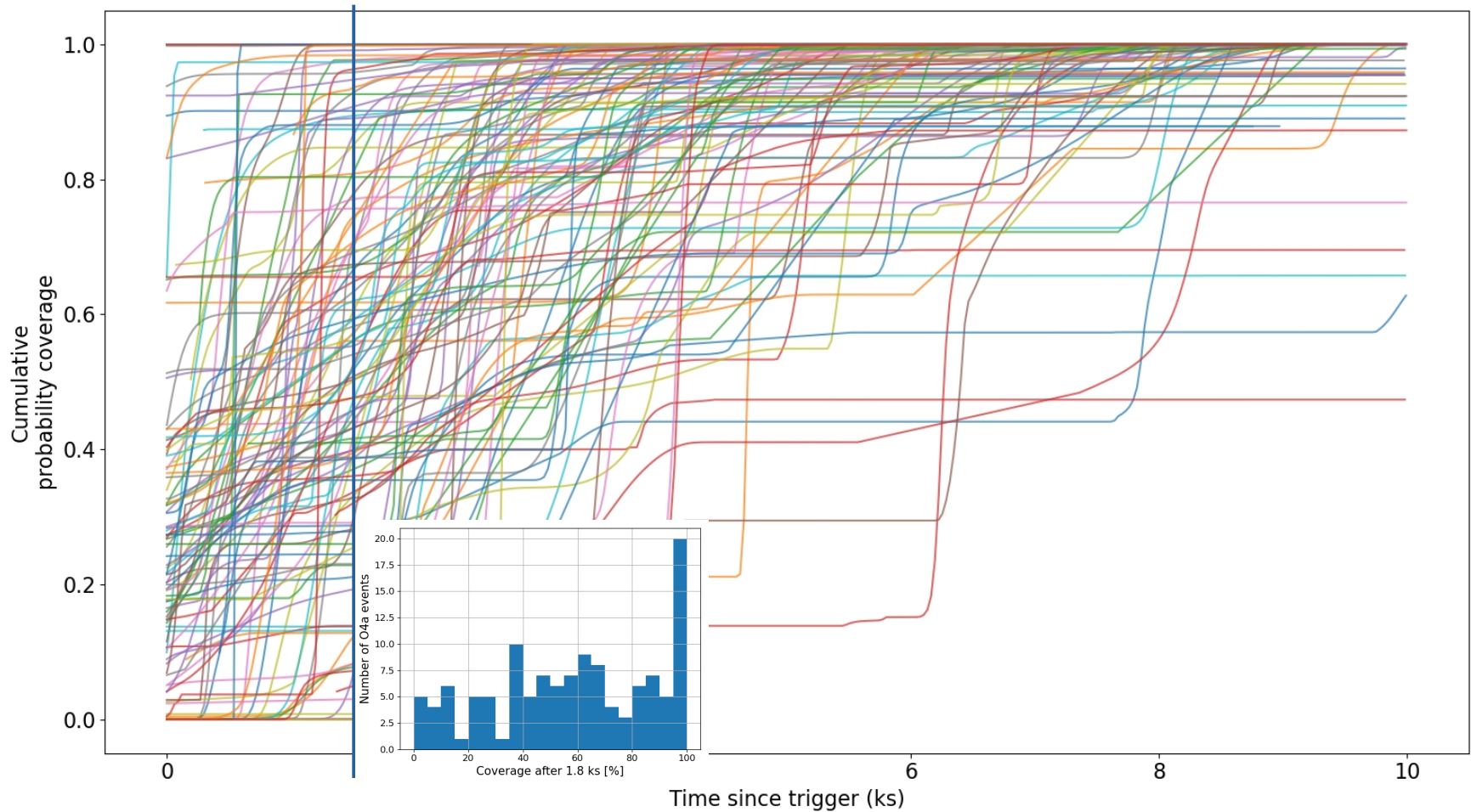




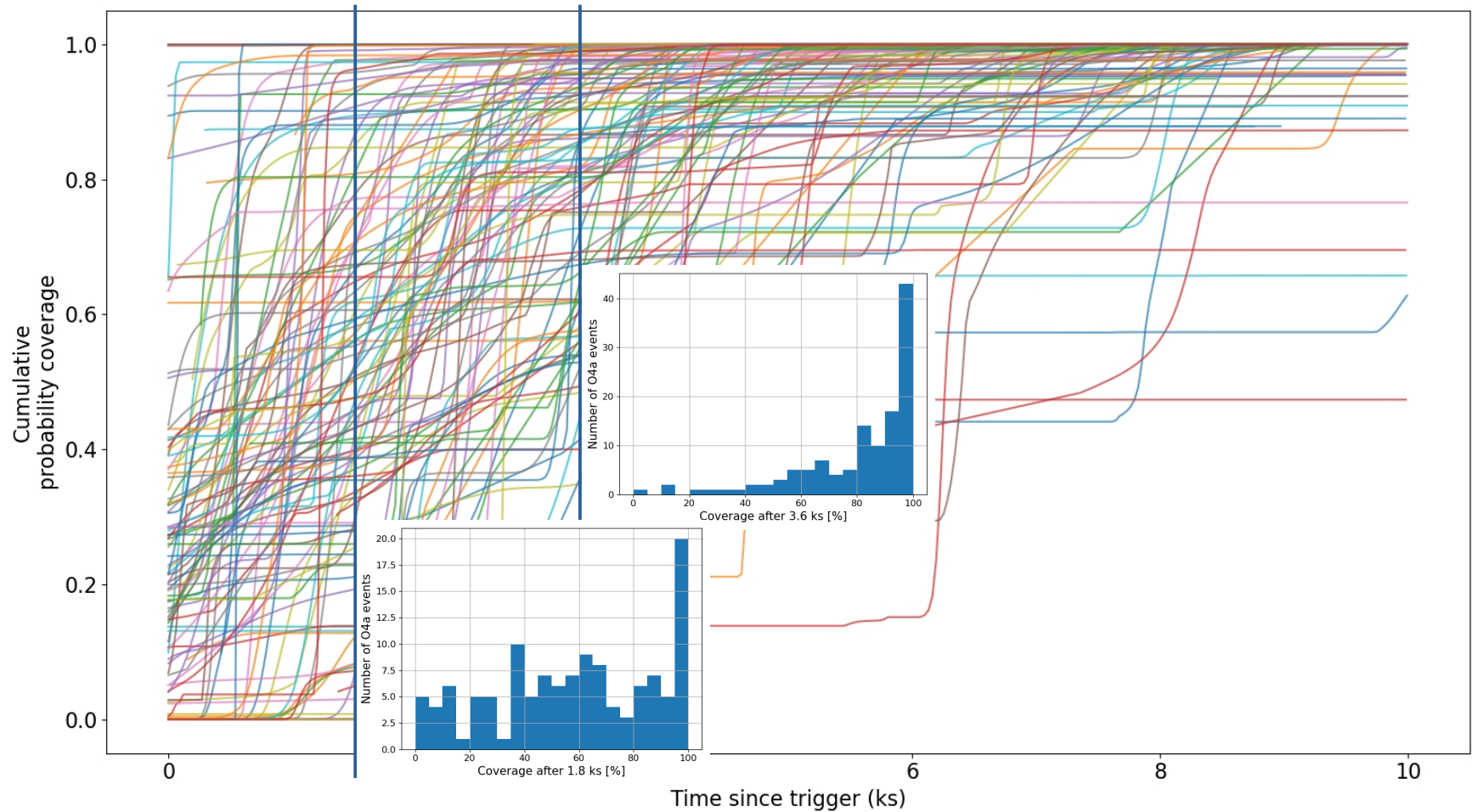
# Cumulative Coverage – Significant GW



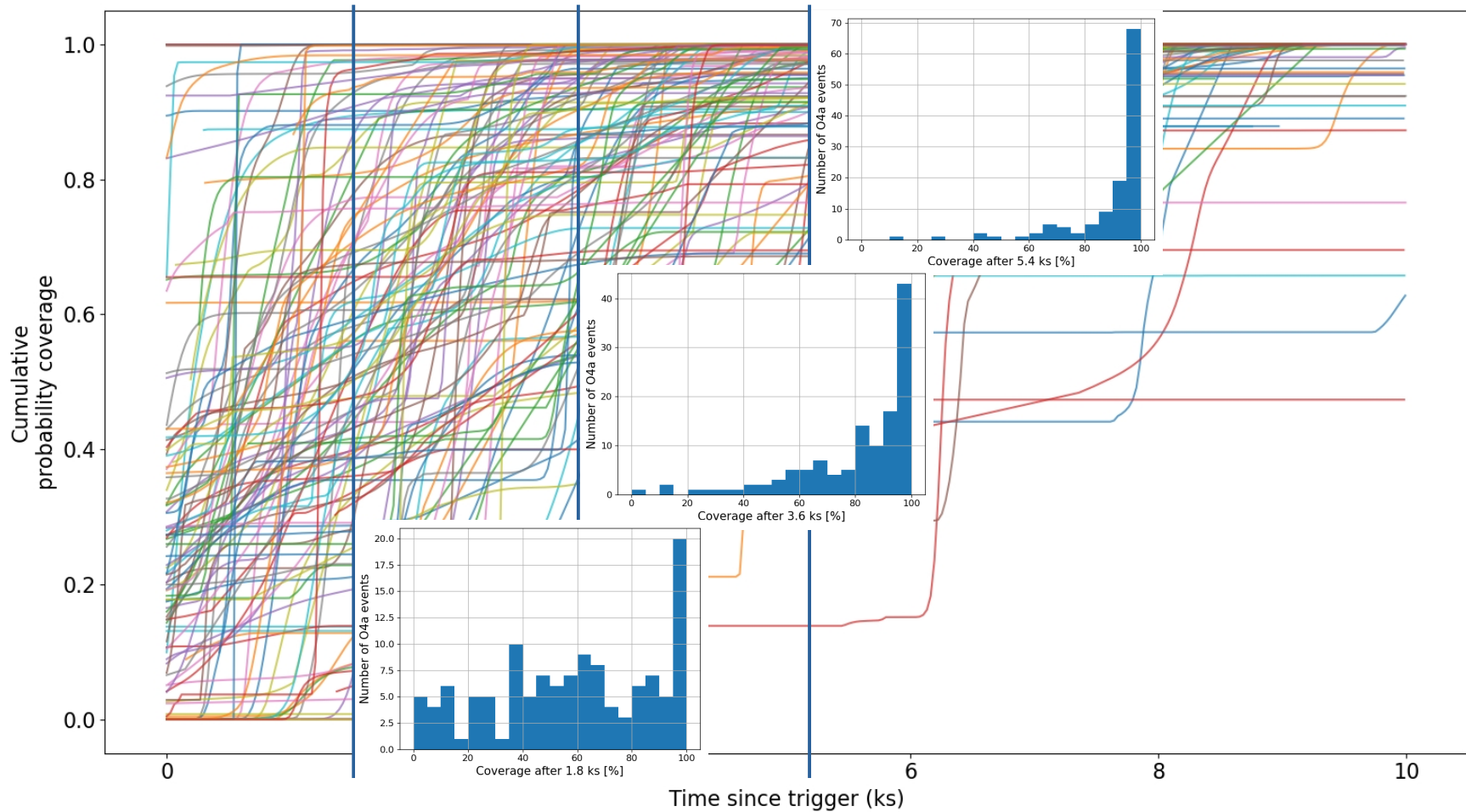
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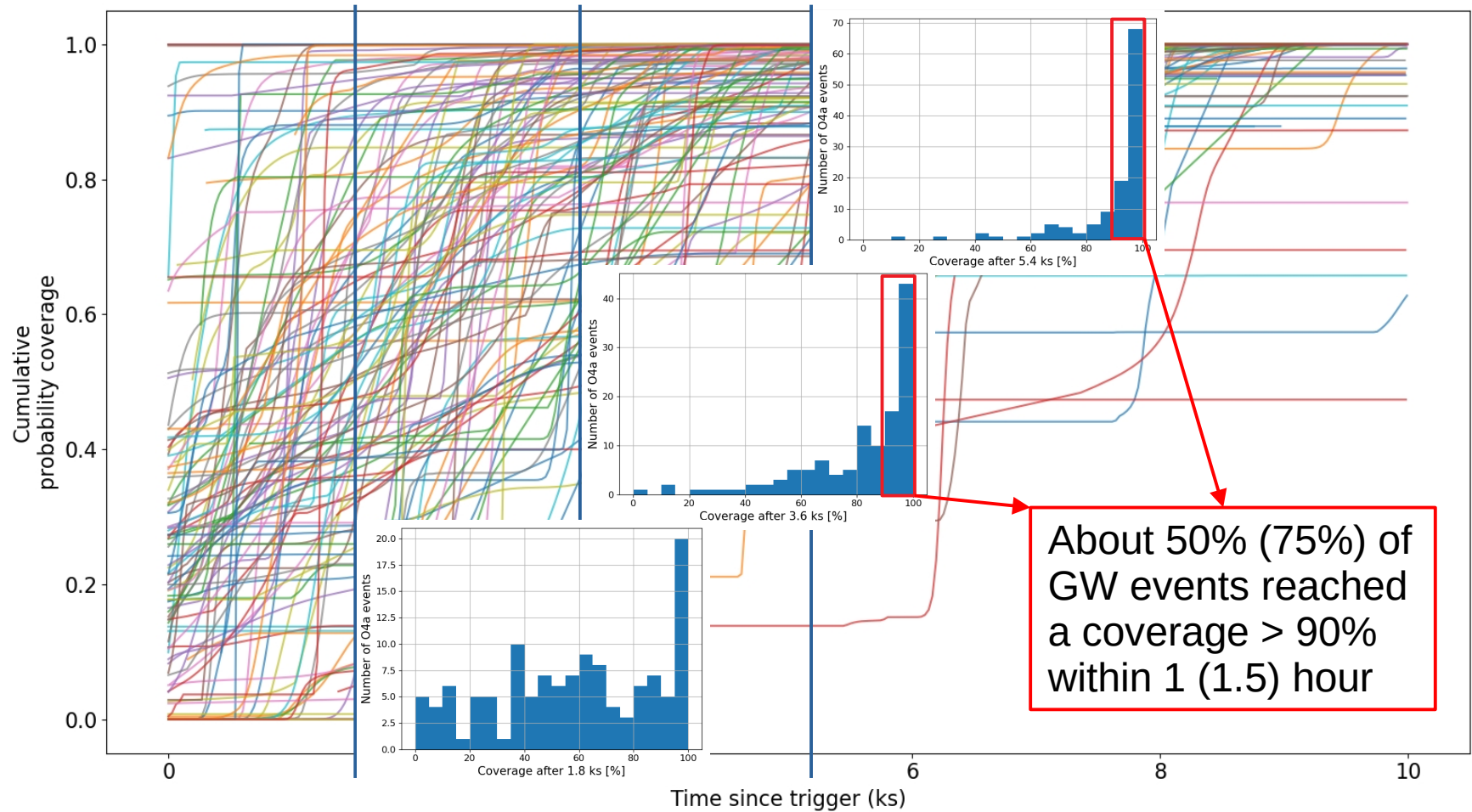
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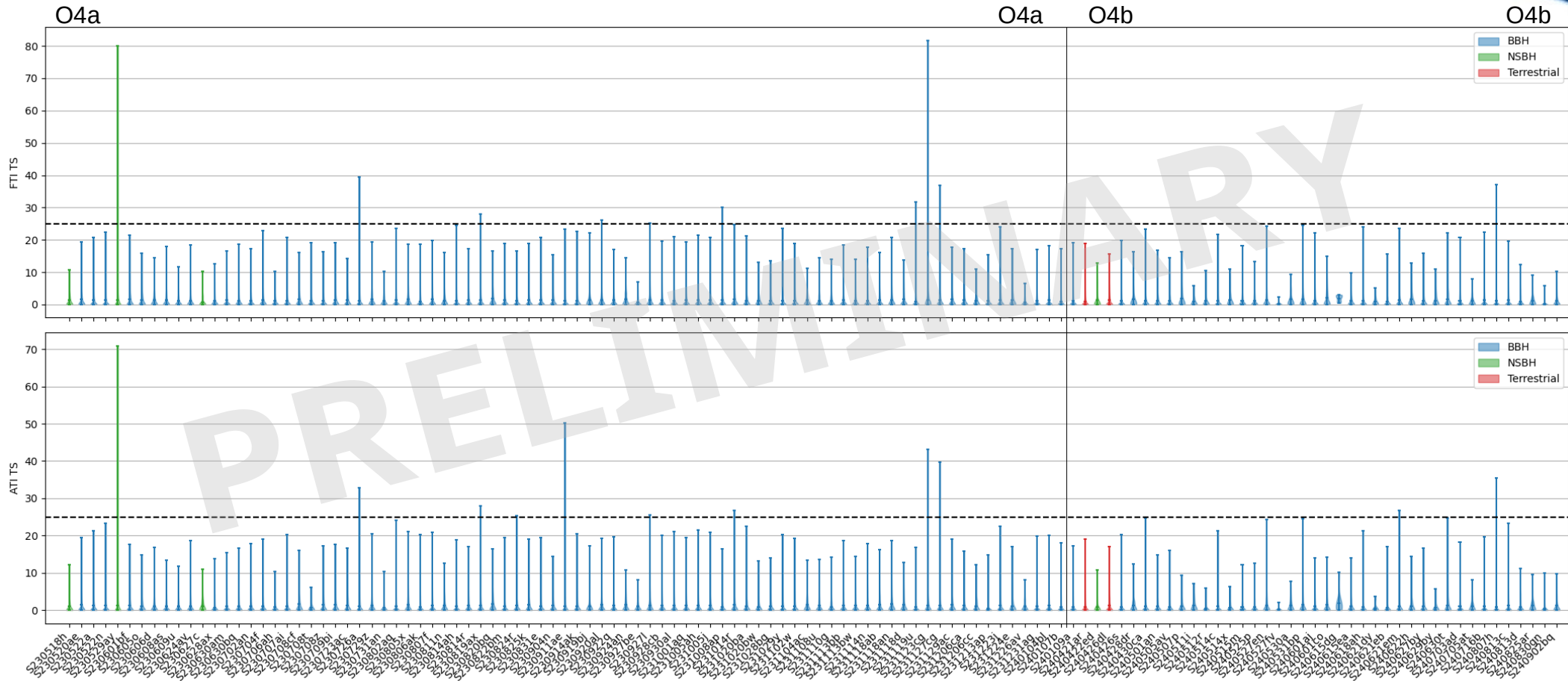
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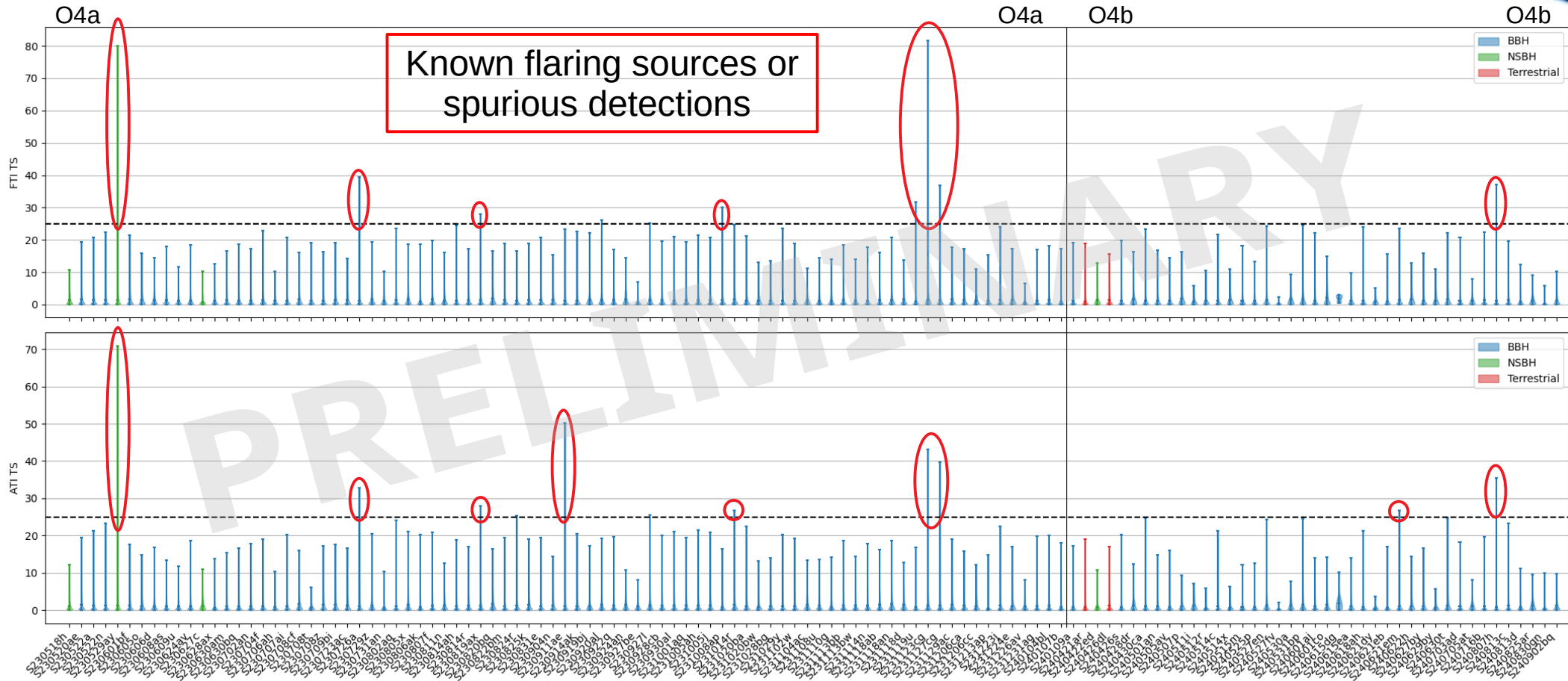
# Cumulative Coverage – Significant GW



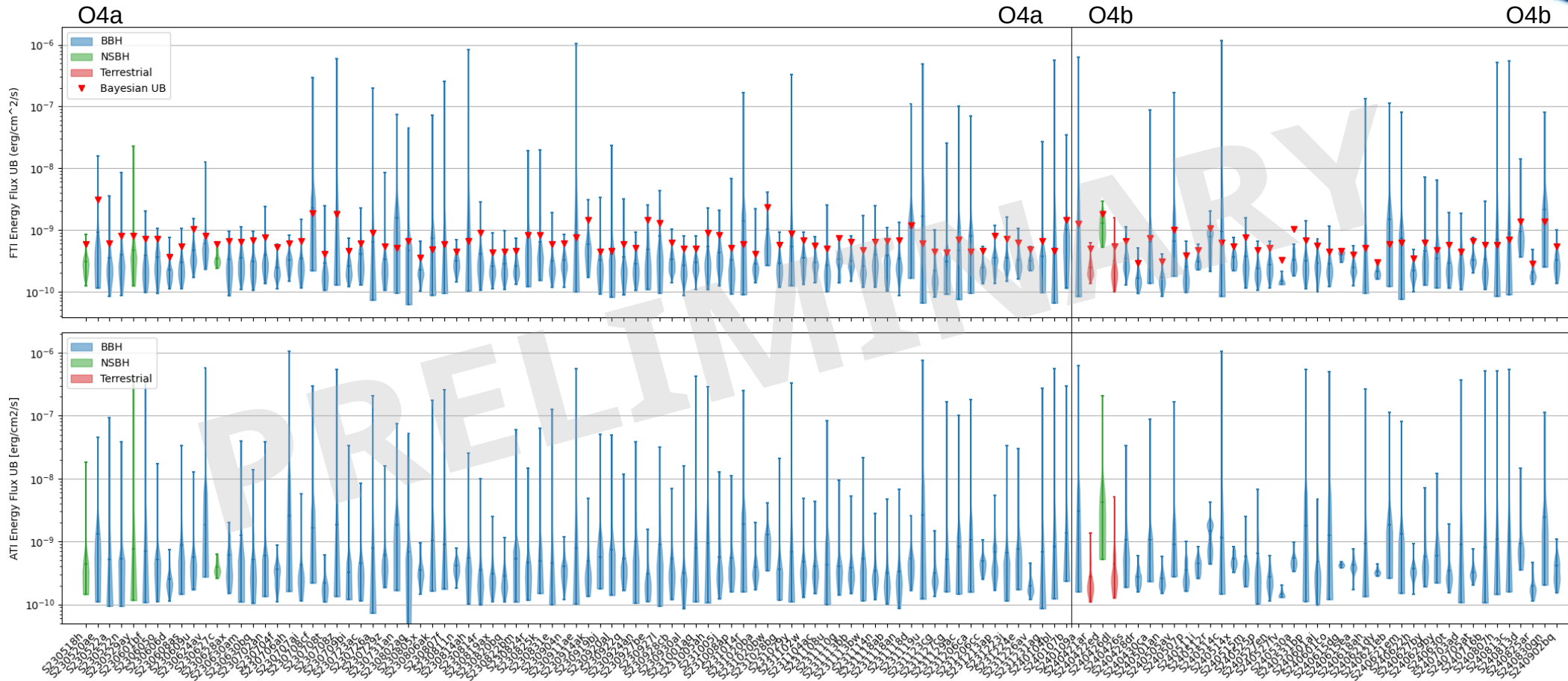
# FTI/ATI TS Distribution – Significant GW



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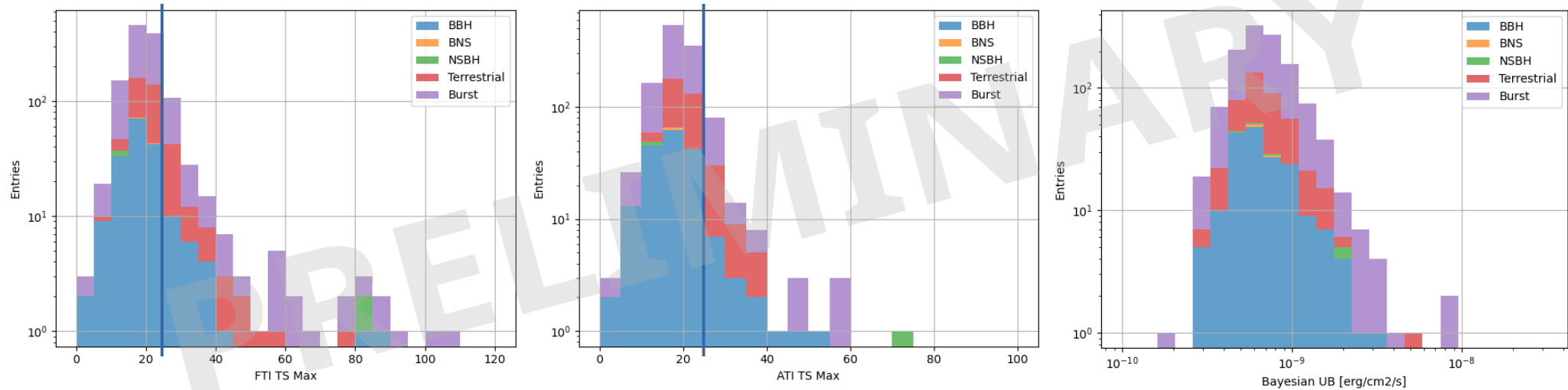
# FTI/ATI Flux UB Distribution – Significant GW





# FTI/ATI TS Max & Bayesian Flux UB

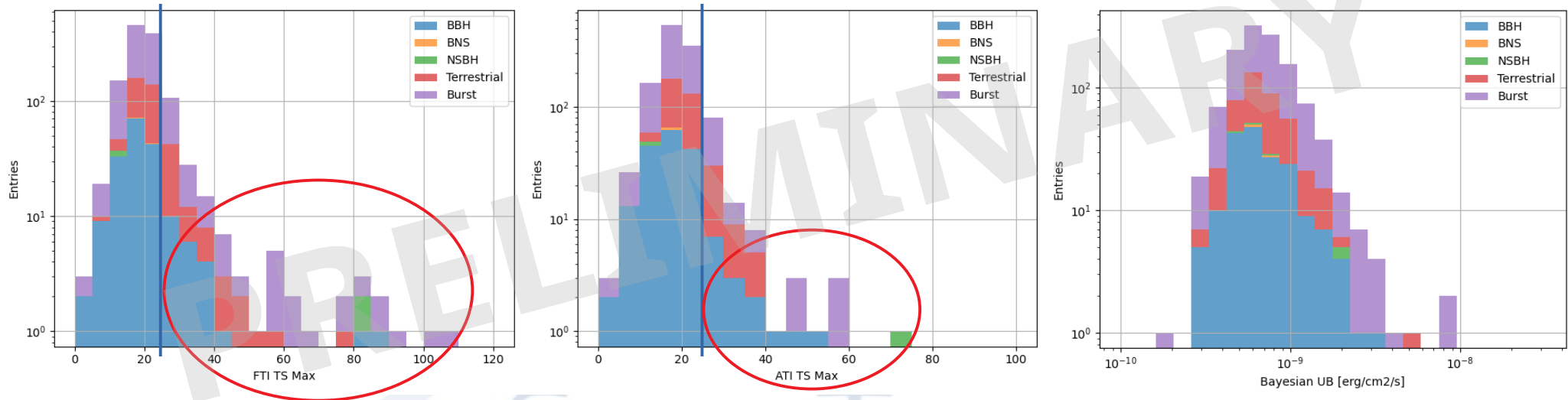
Considering all the GW events followed-up by the LAT



Space Telescope

# FTI/ATI TS Max & Bayesian Flux UB

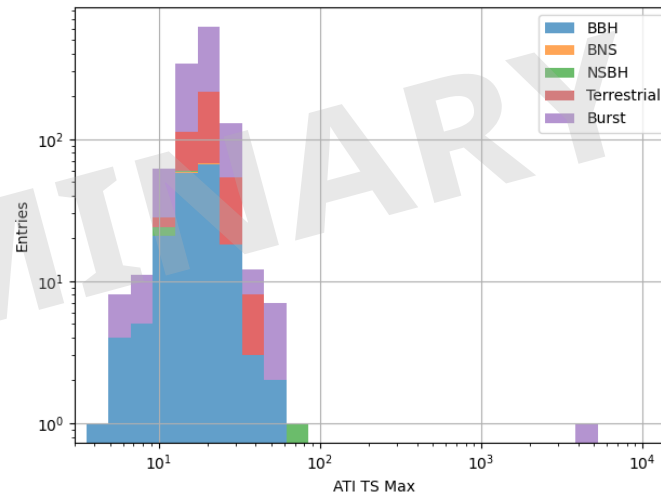
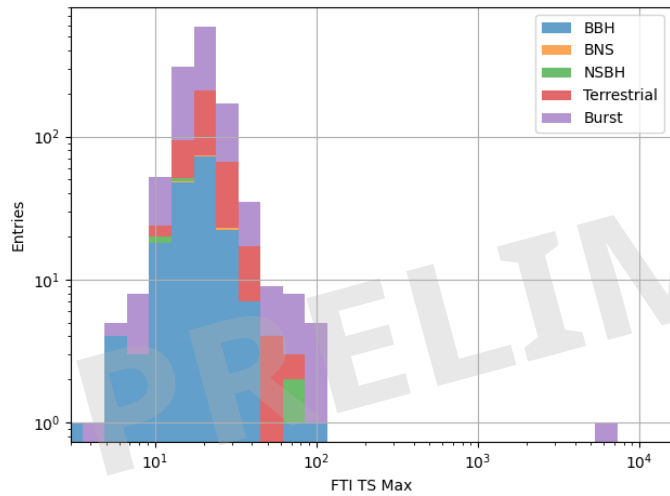
Considering all the GW events followed-up by the LAT



Known flaring sources or spurious detections

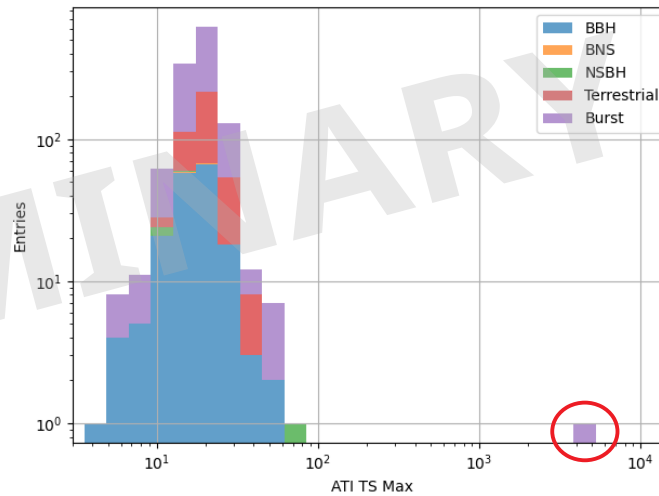
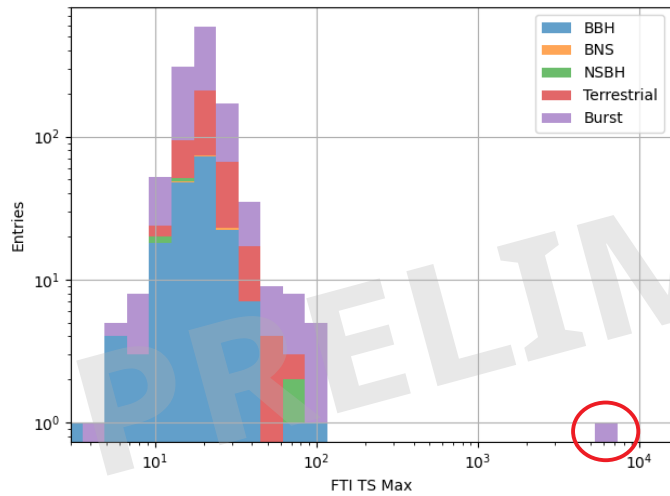
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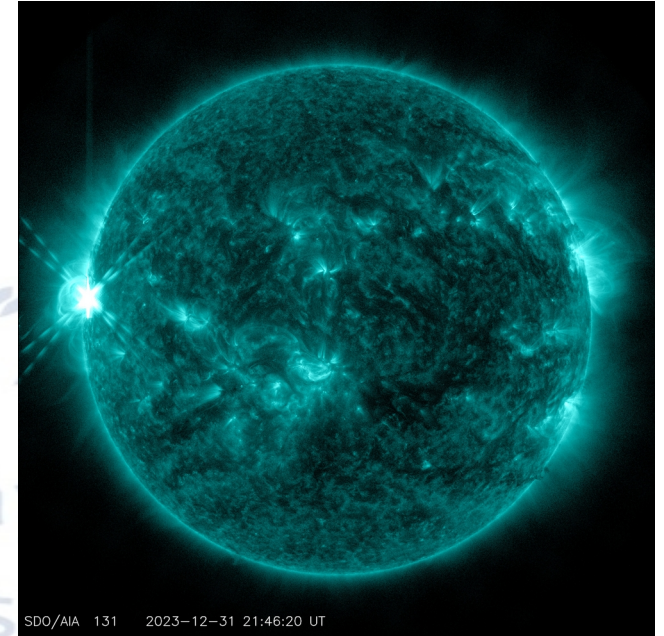


# FTI/ATI TS Max & Bayesian Flux UB

Considering all the GW events followed-up by the LAT



X5 Solar flare 2023-12-31!



Credit: NASA/GSFC/SDO

# Conclusions

- Fermi-LAT successfully followed up around 50% (~1200) of all the GW alerts released during O4 looking for a gamma-ray counterpart:
  - **Including all the significant GW events**
  - Excluding most of the events with Terrestrial probability  $> \sim 80\text{-}90\%$
- **Good and timely high-energy coverage** guaranteed by the LAT:
  - About 50% (75%) of the GW events reached a coverage  $> 90\%$  within 1 (1.5) hour
- **Analysis results ready within 12 hours** of the GW trigger:
  - So far no significant counterparts beside flaring sources or spurious signals have been detected (by any EM telescopes)
  - **Results released on a public webpage** for significant events
  - Gamma-ray flux upper bounds ( $>100$  MeV)  $\sim 10^{-10}\text{-}10^{-9}$  erg/cm<sup>2</sup>/s